

## Issuing the Challenge

In the spring of 2015, the Space Systems Department at the Marshall Space Flight Center issued a call for innovative ideas to help solve a problem at the Flight Robotics Laboratory Flat Floor Facility. The Flat Floor Facility uses air bearings to float heavy payloads on the world's largest air bearing floor. Air bearings generate lift by pumping compressed air through the bearing surface. These bearings can lift heavy loads and allow the test article to be moved across the floor with very little force, allowing testing for the spacecraft Guidance, Navigation and Control (GN&C) systems in a 1g, 2 dimensional environment.

The Marshall Space Flight Center (MSFC) is currently developing several small "cubesat" satellites that will use on-board propellant to maneuver in space. These new propellant systems must be tested, and the flat floor is the perfect place. Some of these small cube satellites can have a mass less than 6 kg. The engineers at the Flight Robotics Laboratory found that connecting air hoses and air bearings, designed for larger equipment testing, to these small, low mass spacecraft hindered the spacecraft's ability to move freely due to forces from the air hoses and weight of the bearings. The Flight Robotics Laboratory issued a call for innovative solutions for GN&C testing of small satellites weighing up to 6 kg.

## Answering the Call

MSFC Employees Alex Few, Judith Gregory, Jacob Kiefer and Paul Tatum formed a multi-disciplinary team to address this problem. Their solution was to use ferro-fluid as the bearing medium instead of air. Ferro-fluid is a liquid that is attracted to magnetic fields. When ferro-fluid is placed on a magnet, it sticks. The magnetic field holds the fluid in place and when the magnet is placed fluid side down on a smooth surface, it glides with very low friction. Paul conducted initial experiments in his home workshop with supplies he purchased and materials at hand. In his initial tests Paul was able to float several pounds of lead weight. Paul



*Figure 1 Ferro Fluid adhered to magnets, bearing 3 lbs. of lead.*

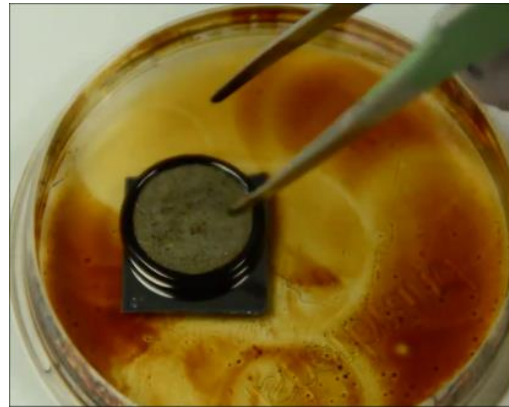
also discovered limitations when working with the fluid; it's messy and it tracks on the test surface.

The Space Systems Department gave the team some funds to purchase stronger magnets and more ferro-fluid, and granted the team members' access to the Flight Robotics Laboratory for testing. The team was able to successfully float 6 kg on the ferro-fluid bearings. During testing the ferro-fluid would deposit onto the test surface, and the team wanted to find a



*Figure 2 Paul demonstrates floating 6 kg of lead ballast. The dark streaks are ferro-fluid being deposited onto the yellow acrylic test surface.*

surface that repels the fluid so that the magnets would easily retain the fluid. This led to discussions with Dr. Anish Tuteja Associate Professor of Materials Science and Engineering at the University of Michigan. Dr. Tuteja sent some samples of omniphobic coated materials that his graduate students have developed. The idea being that the coated surface would repel the fluid, allowing the magnets to retain the fluid and not deposit tracks. Dr. Tuteja's coatings were very cloth like in nature and very repellant to many fluids. However, they did not hold up to applied pressure and when the ferro-bearing was applied to the coated materials, the coating failed under the pressure, soaking up the ferro-fluid. Dr. Tuteja reissued the task to his students to develop a non-compressible coating, and by early fall the students had succeeded by producing a new, smooth, non-compressible, omniphobic coating.



*Figure 3 A magnet holding a ring of ferro-fluid rests on a square sample of material coated with the non-compressible omniphobic coating.*

The most recent coating has shown promising results in limited testing. Figure 3 shows a magnet holding ferro-fluid around the edges sitting atop a square of material with the non-compressible coating. The video provided by the University of Michigan demonstrates how the ferro-fluid is repelled by the coating, allowing the magnet to retain it. NASA and the University of Michigan are currently discussing how to move forward with further development. With a coated test surface and some parts designed for cubesats, this technology will be ready to be released to the consumer. Motion control companies have shown an interest in this technology and with a small amount of further development this process can change the way small satellites test GN&C systems.

The ferro-bearing team was given the freedom and resources to go test some crazy idea; an idea that some said would never work. The team used the limited resources available (the current bill for the entire project is under \$700.00) and developed the process in about 2 weeks. Early failure in the trial phase of the process led to solutions and refinements to the process, creating a cleaner work environment and a relationship with academia. Ongoing research and development, based on failure, encouraged the University of Michigan to develop a new coating suited to the needs of the project. During the initial presentation for the concept, several seasoned engineers informed the team that this would never work, that magnetic fields are too weak, and that magnets are too heavy. The team was able to create a 0.25 kg test fixture that supported the required 6 kg. We dared to try in spite of the advice. When the team discovered that the fluid would stick to the test surface, they tried several coatings (car wax, Rain-X) with minimal success. This led them to seek outside help and build a collaborative relationship with academia. The team was able to learn and develop the process on limited resources. The initial coating failure prompted our partners to press forward with a new solution. When the initial coatings failed the teams persevered until a solution was found.

The innovative behaviors outlined here allowed our team and our partners to create a new process for testing cubesats and micro-propulsion systems and promoted the development of a new, non-compressible, smooth, omniphobic surface coating.